

Geometric distortion of schematic network maps

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The London Underground map is one of the most popular maps of modern times, depicting the lines and stations of London's rail system as a schematic diagram. Its present design is still very similar to Harry Beck's original layout of 1933. The geometry is deliberately distorted to improve readability and facilitate way finding in the network. This short paper presents the visual results of a cartometric analysis of the current London Underground map. The analysis was carried out using MapAnalyst, a specialized program for computing distortion grids and other types of visualizations that illustrate the geometric accuracy and distortion of maps. The described method could help designers of schematic maps to verify their design against the "geometric truth", and guide their choice among different design options.

The London Underground map

The famous London Underground map shows the Thames and named metro stations with railway tracks as straight line segments. Strictly speaking, it is not a map that aims at a metrically accurate depiction of the network, but it is rather a diagram that accentuates the topological relations of Underground stations. Henry "Harry" C. Beck produced the first sketch for the famous diagram in 1931. His first submission was rejected, probably because the schematic 45- and 90-degree design was considered as being too revolutionary. His second submission, however, was published in January 1933 after a few graphical improvements (Garland, 1998). The public quickly adopted Beck's innovative diagram and appreciated its effective information design. Indeed, very soon additional printings had to follow the initial 750,000 copies. Probably one of the main reasons why the public so openly embraced Beck's diagram, was that it brought order into London's intricate geography. Garland 1998:7-8 writes: "Above any consideration of the Diagram as a navigation aid was the optimistic vision it offered of a city that was not chaotic, in spite of appearances to the contrary, that knew what it was about and wanted its visitors to know it, too. Its bright, clean and colourful design exuded confidence in every line."

Beck had been contracted previously as a temporary employee at the Underground Group but designed the diagram in his own spare time on his own initiative, after he had been laid-off. He continued adapting the diagram to the growing railway system and refining the design until 1959, when his last diagram was printed. He even continued his eager work after a redesigned, but rather unaesthetic and unsuccessful diagram was published in 1962, and a much-improved version by Paul E. Garbutt of 1964 demonstrated its effectiveness (Garland, 1998).

The London Underground diagram certainly belongs to the design classics of the twentieth century. It not only affected the design of similar public transport maps around

the globe, but also had an enduring influence on other areas of graphic information design. London Transport, of course, continues improving and extending the diagram map, while still following Harry Beck's initial design.

Besides the ingenious layout of the railway lines at 45- and 90-degree angles, a purposeful enlargement of the central portion of the network is the main characteristic of Harry Beck's diagram. Enlarging the centre in relation to the outlying regions allowed him to include all tentacles of the ramified network, while still clearly depicting the details of the central area. Beck describes the design process as follows: "I tried to imagine that I was using a convex lens or mirror, so as to present the central area on a larger scale. This, I thought, would give a needed clarity to interchange information" (Garland, 1998:17).

At the Institute of Cartography of ETH, we were initially interested in visualising this central enlargement, after having developed MapAnalyst, a software application for the accuracy analysis of maps (Jenny, Weber and Hurni, 2007; MapAnalyst is available at <http://mapanalyst.cartography.ch>). The main purpose of MapAnalyst is the computation of distortion grids and other types of visualizations that illustrate the geometrical accuracy and distortion of maps. While MapAnalyst was developed to cartometrically analyse historical maps, it can also be used to study the distortion of modern maps or other graphics. It uses pairs of control points on the study map and on a reference map, which is considered to be accurate. The program uses the control points to construct distortion grids, vectors of displacement, and isolines of local scale and rotation.

The software uses algorithms developed by D. Beineke to construct distortion grids (Beineke, 2001). Figure 1 shows the distortion grid computed with this algorithm, based on 286 control points that were placed on each station of the modern day Underground map and on the corresponding reference map. The distortion grid of figure 1 clearly visualizes the warping of geographical

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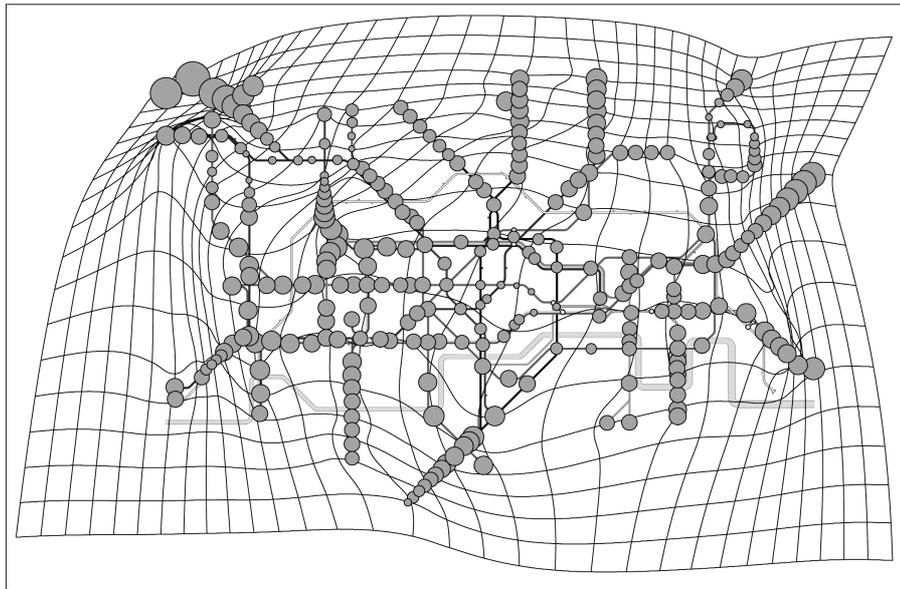


Figure 1 The current London Underground diagram with an overlaid distortion grid and displacement circles. The circles' areas are proportional to the distances to the correct locations.

space that was applied to enlarge the central section. Cells are considerably larger at the centre of the diagram than on the periphery of the network. The grid also points out topological inconsistencies of the diagram in the northwest and the southeast, where grid cells overlap. The grey circles in Figure 1 indicate the positional accuracy of each station. They have been obtained by first applying an affine transformation between the Underground map and the reference map, and then computing the distance between the correct geographic location and the corresponding location on the diagram. These circles only partially confirm the assumption that more remote stations are positioned less accurately. This is clearly the case in the north-western "Metropolitan" line, but not so for the southern branch of the "Northern" line, where the terminal on the diagram is actually quite close to its true geographic location

Figure 2 shows again a distortion grid and displacement circles as Figure 1, but this time in the coordinate system of the reference map. Hence, large grid

cells on the periphery show areas that are highly compressed on the diagram, and vice versa. The circles form strings that let the observer easily guess the run of the tracks in outer areas of the map. Their size is again proportional to the distance to the correct locations measured in the coordinate system of the Tube map.

The displacement vectors of Figure 3 further specify the positional accuracy of the Underground stations. Each arrow starts at a station and points at its correct geographic location. MapAnalyst again applies an affine transformation to compute the arrows. Striking are the long vectors in the north-western corner, and the fact that arrows often show a regular pattern along a single line. For example, the easternmost branch would be represented by an almost horizontal line on a geometrically accurate map, but is north-eastern bound on the diagram.

Figure 4 illustrates the important enlargement of the central part of the map and the compression of outer areas. The variable scale of the map is visualized by scale isolines, where percentages indicate scale reduction



Figure 2 The distortion grid for the London Underground diagram in the coordinate system of the reference map. The circles' areas are proportional to the distances to the correct locations measured in the coordinate system of the Tube map.



Figure 3 Displacement vectors. Arrows point at the correct geographic location of each station.

relative to the central area of the map. The equidistance between two neighbouring lines corresponds to a difference of 25% in scale. A value of 100% was assigned to the isoline representing the largest scale. MapAnalyst uses a method based on local affine transformations to compute this novel type of visualisation (Jenny, Weber and Hurni, 2007).

Computer-aided design of schematic maps

Designing a new transport diagram or updating an existing one is a demanding and laborious process (Avelar and Hurni 2006), which could possibly be facilitated by the use of illustrations presented above. Distortion grids, displacement vectors and scale isolines could serve as a tool during the design process by helping locate excessively compressed, enlarged or distorted areas. Such graphics are particularly important when using automated approaches for the generation of schematic maps. Cabello et.al. (2001), Avelar (2002) as well as Stott and Rodgers (2005) published methods for the computer-automated production of schematic transport maps. Distortion grids and displacement vectors presented above can be used to visually verify the output of such programs.

Tom Carden (2006) takes one further step by automatically generating schematic transport maps in real time. His Java applet distorts the network according to travel time, which can also be visualised by isochrones (see also Street, 2006). Figure 5, for example, shows the travelling time when boarding the London Underground at

the Heathrow Airport. The illustrations were generated with Carden's on-line tool available at www.tom-carden.co.uk/p5/tube_map_travel_times/applet/ and www.tom-carden.co.uk/p5/tube_map_travel_times_texture_grid/applet/.

Conclusion

The visualisations presented are not only interesting devices to analyse the geometric distortions of existing transport diagrams, but can also be seen as a valuable tool to design a new schematic diagram or update an existing one. They facilitate the detection of topological conflicts in the diagram and provide easily readable visualisations of the geometric distortions. In short, they serve as tools for controlling the quality of schematic transport maps. Monitoring the quality of schematic transport diagrams is particularly important when using automated methods for the production, since such algorithms appear as black boxes, if the algorithm is either not publicly available, or requires profound programming knowledge.

If we further develop the idea of using distortion grids or displacement vectors during the design process, we may imagine future software applications, where such graphics are not only used for visualisation and controlling purposes, but could also serve as interactive control device for the semi-automatic generation of schematic maps. With such software, the designer of the map could interactively steer the otherwise automated generation of schematic maps by adding constraints. The designer could,

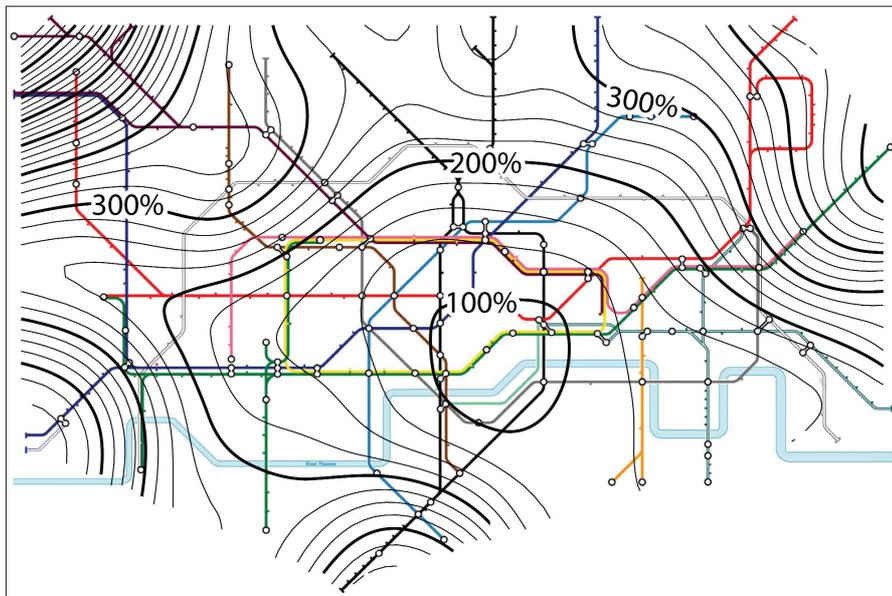


Figure 4 Scale isolines: outer areas are represented at a much smaller scale. Percentages indicate scale reduction relative to the central area of the map.

for example, define zones that should be depicted at large or small scale, or points that should not be moved. There are, however, still many steps to master before arriving at a functional authoring system for the interactive computer-assisted design of schematic transport map.

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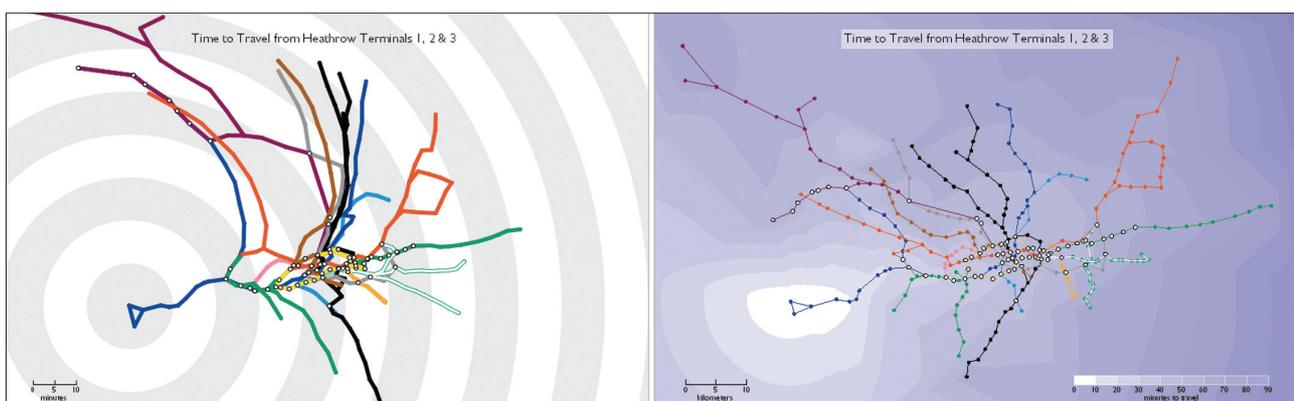


Figure 5 Travelling time isolines for Heathrow Airport. Left: Distorted network with circular isochrones. Right: Irregular isochrones for the undistorted network. From Carden (2006), used with permission.